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# Influence of quinoa roasting on sensory and physicochemical properties of allergen-free, gluten-free cakes

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**Abstract**

The objectives of this study were to determine pasting properties of non-roasted (NR) and roasted quinoa (RQ) and to investigate the effect of RQ on consumer acceptance and physicochemical properties of an allergen-free, gluten-free cake formulation. Quinoa seeds were roasted at 177 °C for 15 (R15), 30 (R30) and 45 min (R45), and flours were analysed for pasting properties. Five cakes including a commercial chocolate cake (CCC) and cakes made with NR and RQ flours were evaluated for preference by fifty panelists. Quality parameters included colour, water activity, moisture content, firmness, weight and height. Peak and final viscosity increased with roasting time. The NR cake had the highest sensory scores for appearance, colour and texture. On flavour and overall acceptability, CCC was the highest. Regarding quality data, CCC, NR and R15 cakes had similar $L^*$ values, while CCC had the lowest $a^*$, $b^*$, $a_w$, moisture content and firmness values.

**Keywords**

Cake, Coeliac, Gluten-free, Quinoa, Roasting

**Disciplines**

Agriculture | Bioresource and Agricultural Engineering | Food Processing

**Comments**

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Original article

# Influence of quinoa roasting on sensory and physicochemical properties of allergen-free, gluten-free cakes

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**Summary** The objectives of this study were to determine pasting properties of non-roasted (NR) and roasted quinoa (RQ) and to investigate the effect of RQ on consumer acceptance and physicochemical properties of an allergen-free, gluten-free cake formulation. Quinoa seeds were roasted at 177 °C for 15 (R15), 30 (R30) and 45 min (R45), and flours were analysed for pasting properties. Five cakes including a commercial chocolate cake (CCC) and cakes made with NR and RQ flours were evaluated for preference by fifty panelists. Quality parameters included colour, water activity, moisture content, firmness, weight and height. Peak and final viscosity increased with roasting time. The NR cake had the highest sensory scores for appearance, colour and texture. On flavour and overall acceptability, CCC was the highest. Regarding quality data, CCC, NR and R15 cakes had similar $L^*$ values, while CCC had the lowest $a^*$, $b^*$, $a_w$, moisture content and firmness values.

**Keywords** Cake, coeliac, gluten-free, quinoa, roasting.

## Introduction

Quinoa (*Chenopodium quinoa*) has been a staple crop of the Andean region of South America for thousands of years. Quinoa has been growing in popularity, and the United Nations has recently named 2013 the 'International Year of Quinoa' (United Nations, 2012). While most quinoa is still grown in the high-altitude regions of South America, it is also cultivated in the USA (Colorado and California), China, Europe, Canada and India (Abugoch James, 2009). Nutritional and functional properties of quinoa have previously been reviewed (Koziol, 1992; Ahamed *et al.*, 1998; Repo-Carrasco *et al.*, 2003; Bhargava *et al.*, 2006; Abugoch James, 2009; Jancurová *et al.*, 2009; Vega-Gálvez *et al.*, 2010; Omary *et al.*, 2012). Quinoa is a highly nutritious food, containing a favourable amino acid profile which includes lysine, an amino acid generally missing from cereal grains (Prakash & Pal, 1998; Oshodi *et al.*, 1999; Comai *et al.*, 2007; Abugoch *et al.*, 2008) as well as fibre, B vitamins, vitamins C and E, copper, zinc, magnesium, potassium, essential fatty acids and antioxidants including phenolic compounds, flavonoids and carotenoids (Koziol, 1992; Wood *et al.*, 1993; Lintschinger *et al.*, 1997; Qian & Kuhn, 1999; Zhu *et al.*, 2001; Tang *et al.*, 2002; Wright *et al.*, 2002b; Ogungbenle, 2003; Lindeboom *et al.*, 2005; Gorinstein *et al.*, 2008; Dini *et al.*, 2010); thus, continuing research is needed to maximise its potential as part of a modern diet.

The definition of gluten-related disorders was recently expanded to include not only autoimmune conditions (coeliac disease, dermatitis herpetiformis or gluten ataxia) and allergic reactions (wheat allergies), but also immune-mediated reactions (gluten sensitivity) that appear to involve neither autoimmune nor allergic mechanisms (Sapone *et al.*, 2012). The cause of gluten sensitivity, which affects up to 6% of the U.S. population (Volta *et al.*, 2013) is not yet clearly understood and is currently the subject of ongoing research aimed at identifying the mechanisms of the disorder. The only treatment for gluten-related disorders is to follow a lifelong gluten-free (GF) diet and people on this diet may be at risk for multiple nutrient deficiencies (Hallert *et al.*, 2002).

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Allergies to eggs and dairy are also problematic, particularly in children, with approximately 1–3% of children being allergic to eggs and cow's milk (Sicherer & Sampson, 2006; Crisafulli *et al.*, 2012). Allergic reactions to quinoa have been reported (Yotaro, 2002; Astier *et al.*, 2009); however, these appear to be extremely rare.

The absence of structure-forming gluten proteins poses unique technological challenges in producing high-quality GF products (Sedej *et al.*, 2011). Alvarez-Jubete *et al.* (2010) conducted a review of the nutritive value of pseudocereals including amaranth, quinoa and buckwheat as functional GF ingredients and highlighted their high-quality protein and significant presence of fibre, calcium, iron and bioactive compounds. Matos & Rosell (2014) published a review of GF dough and its effects on bread-making and reported that textural parameters of GF crumbs are strongly correlated with dough consistency and starch retrogradation, specifically, low dough consistency and minimal retrogradation values are related to softer crumbs. They also reported a need for a higher nutrient quality of GF ingredients as a GF dietary pattern is often characterised by a reduced intake of complex carbohydrates, dietary fibre, vitamins and minerals. At the same time, formulating dairy-free (DF) and egg-free (EF) baked goods is difficult due to the exclusion of critical structural proteins along with other functions attributed to these ingredients. Previous research on GF, DF and EF baked goods has yielded mixed results.

Gluten-free cakes and muffins have been studied by Sae-Eaw *et al.* (2007), Gómez *et al.* (2008), Gambus *et al.* (2009), Ronda *et al.* (2009), Gorgônio *et al.* (2011), Preichardt *et al.* (2011), Ronda *et al.* (2011), Gularte *et al.* (2012a,b), Park *et al.* (2012), de la Hera *et al.* (2013), Shevkani & Singh (2014), Singh *et al.* (2015). On the other hand, EF cakes and muffins have been reported by Arozarena *et al.* (2001), Kaur *et al.* (2005), Hussain & Al-Oulabi (2009), Ashwini *et al.* (2009), Ratnayake *et al.* (2012) and Singh *et al.* (2015).

At the same time, different processing methods have been found to affect the nutritional, sensory and physicochemical characteristics of vegetables, coffee, legumes, nuts, cereals and oats (Oenning *et al.*, 1994; Griffith & Castell-Perez, 1998; Zia-ur-Rehman *et al.*, 2003; Zhang & Hamauzu, 2004; Martins & Gloria, 2010; Sharma *et al.*, 2011). Brady *et al.* (2007) reported degradation of saponins in roasted quinoa, and Repo-Carrasco-Valencia *et al.* (2010) measured mineral availability after boiling and roasting quinoa. Roasting of seeds is often done to enhance flavour and reduce antinutrients such as phytic acid and saponins (Gahlawat & Sehgal, 1993; Griffith & Castell-Perez, 1998). The effect of roasting on antioxidant capacity, mycotoxins and food quality has been reported for wheat, barley, green gram, peanuts, coffee and hazelnuts (Buckholz *et al.*, 1980; Gahlawat & Sehgal, 1993; Nicoli *et al.*, 1997; Richardson & Ebrahem, 1997; Daglia *et al.*, 2000; del Castillo *et al.*, 2002), but not yet for quinoa.

Many of the studies on allergen-free (AF) or GF products reported above are based on alternative refined flours (i.e. rice, corn, etc.), thus data on the development of nutrient-dense, whole-grain and fibre-rich GF baked goods with sensory and quality properties similar to those baked goods containing gluten are lacking. The goals of this study were to evaluate the effects of roasting of quinoa on pasting properties of the resulting flours, along with sensory and physicochemical properties of allergen-free, gluten-free cakes (AF-GF) made with these flours. To the authors' knowledge, these investigations have not been reported.

## Materials and methods

### Materials

Unroasted and roasted quinoa (*C. quinoa*) (Sprouts Farmers Market, Phoenix, AZ, USA), whole-grain milk (blend of brown rice, amaranth, millet and quinoa), cocoa powder, agave syrup, maple syrup, grapeseed oil, apple cider vinegar and sea salt (Trader Joes, Monrovia, CA, USA), navy bean flour (Inland Empire Foods, Riverside, CA, USA), baking powder (Clabber Girl, Terre Haute, IN, USA), and baking soda and vanilla extract (Stater Brothers, Colton, CA, USA) were used in the preparation of the cakes. See Table 1 for cake formula used in this study.

*Roasting of quinoa*

Stoneware trays 29.2 cm × 19.7 cm (Pampered Chef®, Addison, IL, USA) lined with aluminium foil were

**Table 1** Formula for AG–GF cakes

| Ingredient | Amount, g | As formulated basis (%w/w) | % Flour basis (%w/w) |
|---|---|---|---|
| Quinoa flour | 295.88 | 21.8 | 79.1 |
| Navy bean flour | 78 | 5.7 | 20.9 |
| Cocoa powder | 51.45 | 3.8 | 13.8 |
| Baking soda | 10.14 | 0.7 | 2.7 |
| Baking powder | 8.8 | 0.6 | 2.4 |
| Sea salt | 6.13 | 0.5 | 1.6 |
| Whole-grain milk | 475.56 | 35.0 | 127.2 |
| Grapeseed oil | 86.43 | 6.4 | 23.1 |
| Maple syrup | 135.45 | 10.0 | 36.2 |
| Agave nectar | 203.08 | 15.0 | 54.3 |
| Apple cider vinegar | 4.64 | 0.3 | 1.2 |
| Vanilla extract | 2.37 | 0.2 | 0.6 |
| Total | 1357.93 | 100 | 363.2 |

AG–GF is allergen-free, gluten-free.

 

used. Two hundred and fifty grams (250 g) of unroasted quinoa was used per tray and per batch. Whole quinoa seeds were roasted at 177 °C for 15 (R15), 30 (R30) and 45 min (R45) in a convection oven. Both unroasted and roasted quinoa were milled in a grain mill (Model GMA, KitchenAid, St Joseph, MI, USA) using the finest setting in all cases (refer to particle size analysis described below). Triplicate batches were prepared per treatment and analysed along with three different lots of commercial quinoa flour (CQF).

## Analysis of quinoa flour

*Particle size analysis*

Samples were run in a laser diffraction particle size analyser (LA-950V2; Horiba Instruments, Irvine, CA, USA) using 70% ethanol and 30% deionised water solution as the carrier medium. A sample was placed into the mixing vessel, and the solution was agitated and treated with ultrasonics (30 s) to break up clumps prior to analysis. A total of three replicates of each sample were analysed.

*Pasting properties*

Sample suspensions containing 10% dry solids (28 g total weight) in phosphate buffer solution (pH 6.5) were measured in a Rapid Visco Analyser (RVA-4; Newport Scientific, NSW, Australia) using the STD1 pasting profile (AACC Method 76-21.01, ICC Standard No. 162, 2000)). The suspension was equilibrated to 50 °C at 960 r.p.m. stirring for 10 s, heated to 95 °C at a rate of 15 °C $\text{min}^{-1}$ and held at 95 °C for 10 min. The suspension was then cooled to 50 °C at a rate of 15 °C $\text{min}^{-1}$ and held at 50 °C for 2 min. After equilibration, the stir speed during the test was 160 r.p.m.

## Cake preparation

Due to this cake formula being free of allergen-containing ingredients such as milk, butter, eggs and wheat, an alternative to the standard AACC cake formulation methods were needed. The formula and procedure for baking the allergen-free gluten-free cakes were based on the method by Hoover (2009) with some ingredient modifications (Table 1). The amount of quinoa was kept constant in all treatments. Quinoa and navy bean flours as well as whole-grain milk were used instead of oat flour and coconut milk, respectively. A Kitchen Aid Mixer (Model K45SS, St. Joseph, MI, USA) using setting 4 was used for cake mixing. Cakes were baked in triplicate in aluminium pans (23 cm × 13 cm × 8 cm – L × W × H) at 177 °C for 40 min. Cakes were allowed 30 min to cool to room temperature before conducting any testing.

## Cake analyses

*Sensory evaluation*

Fifty (50) untrained panellists including students, faculty and staff from Cal Poly Pomona evaluated five (5) randomly presented cake samples (~10 g) including a cake made with NR quinoa, cakes made with the roasted quinoa (R15, R30 and R45) and an external control made from chocolate cake by a grocery chain (Costco, Riverside, CA, USA), for overall acceptability, appearance, colour, flavour and texture using a nine-point hedonic scale. Samples were served at room temperature (25 °C).

*Colour*

CIELab colour was measured using a Minolta Chroma Meter (Model CR-410; Konica Minolta Sensing Americas, Inc., Ramsey, NJ, USA), calibrated using a Minolta white calibration plate No. 17333240 for CR-200/CR-300/CR400 with 2° OBSERVER to measure lightness which ranges from 0 (black) to white (100) ($L$*), red(+)/green(−) ($a$*) and yellow(+)/blue(−) ($b$*) colour values. Colour readings were collected from the middle section/crumb of three (3) cakes.

*Water activity*

Water activity of cakes was measured on three (3) cakes per treatment with a water activity meter (AquaLab v.2.0; Decagon Devices, Inc., Pullman, WA, USA) at 25 ± 0.2 °C. Samples were collected from the middle section of each cake.

*Moisture content*

Cake moisture content was measured on three (3) cakes per treatment with a moisture balance (Model MOC-120H; Shimadzu, Kyoto, Japan). Samples were collected from the middle section of each cake.

*Firmness*

Cake firmness was determined using the AIB standard procedure using a texture analyzer (model TA.XT plus; Texture Technologies Corp., Scarsdale, NY, USA/Stable Micro Systems, Godalming, Surrey, UK). Nine readings were obtained per treatment.

*Weight and height*

Cake weight and height were determined on three (3) cakes per treatment. Height was measured with a ruler in the middle section of the cake.

*Cake nutritional information*

Nutritional information was generated per 80 g of reference amount customarily consumed (RACC) and from calculations based on ingredients and quinoa analysis using Genesis RQL (Version 9.10 ESHA, Salem, OR, USA).

### Experimental design and statistical analysis

Five treatments were used in this experiment, four cakes made with nonroasted (internal control) and roasted quinoa at different roasting times (NR, R15, R30 and R45, respectively) along with an external control or commercially made chocolate cake containing eggs, milk and wheat flour (CCC) as no gluten-free, allergen-free cake was commercially available. All cake and flour data were analysed using a generalised linear model in SAS v 9.2 (SAS Institute, Cary, NC, USA), with a Type I error rate ($\alpha$) of 0.05 to determine whether differences among mean values occurred. If differences among means were present, then *post hoc* least significant difference (LSD) testing was conducted (again, at $\alpha = 0.05$) to determine where these differences occurred.

## Results and discussion

### Analysis of quinoa flour

*Particle size analysis*

Geometric mean diameters were 794, 802, 664, 578 and 197 µm for nonroasted (NR), R15, R30, R45 and CQF, respectively (data not shown). Geometric mean diameters were not significantly different ($P > 0.05$) between NR and R15, but decreased after 30 min of roasting. The elevated roasting temperature for longer than 15 min may have caused the weakening of starch–protein interactions and swelling of the starch granules, leading to granule rupture and decreased geometric mean diameters (Kim *et al*., 2004).

*Pasting properties*

Pasting temperature was similar among all treatments (~50.1 °C) (Table 2 and Fig. 1). Peak viscosity, an indicator of water-binding capacity, gel strength and elasticity had the highest values among NR and CQF quinoa samples (12 433 cP) and increased with roasting time from 9328 cP (R15) to 15 585 cP (R45) showing increased water-binding capacity. Peak viscosity was achieved when the rate of starch granule swelling (and thus increase in viscosity) was equal to the rate of breakdown of the granules (Crosbie & Ross, 2007). Representative pasting curves are shown in Fig. 1. The NR curve was typical of a starch, with a sharp peak demonstrating a fast transition from swelling to breakdown of the granules. As roasting time increased to 15 min, the starch became more stable, as evidenced by an increasingly smooth peak, and decreasing breakdown values. Beyond 15 min of roasting, a distinct peak was not quantifiable, as breakdown values were not observed. Peak values reported are the highest values measured during the constant temperature phase of the analysis. During roasting, loosely packed starch granules that are partially gelatinised and easily damaged hydrate and swell rapidly in the presence of heat and water and consequently produce a lower peak viscosity. Trough viscosity, or the resistance to breakdown during cooling, showed no statistical differences between NR and R15 (8931 cP). Breakdown viscosity is a calculation of peak minus trough viscosities. Roasting for 15 min drastically reduced breakdown values, indicating a greater ability to withstand stress during cooking. Beyond 15 min (R30 and R45), no breakdown was observed. Setback (a calculation of final minus trough viscosity) indicates the degree of retrogradation in the cooling starch, which may or may not be desirable in a food product. Gelatinisation (loss of orderly structure which leads to irreversible swelling of the granules) occurred in NR, CQF and to a lesser degree R15, as there was considerable retrogradation; however, this was not seen with longer roasting times. Final viscosity, an indication of the stability of the cooked paste, increased with roasting time from 14 596 (NR) to 24 344 cP (R45), while CQF had the lowest values at 11 641 cP. It appeared that as roasting time increased, the starches were modified, as evidenced by an increasingly smooth transition from peak viscosity to the final viscosity. Food products may possibly benefit using a combination of roasted and nonroasted flours for products that require gelatinisation, but without excessive retrogradation.

These results were approximately threefold higher than findings from previously published pasting data (Qian & Kuhn, 1999; Wright *et al*., 2002a; Lindeboom *et al*., 2005). This may be due to a number of factors.

**Table 2** Pasting properties of quinoa measured by rapid visco analyzer

| Sample | Peak | Trough (cP) | Breakdown (cP) | Setback (cP) | Final viscosity (cP) | Peak time (Min) | Pasting temp (°C) |
|---|---|---|---|---|---|---|---|
| NR | 11 922$^{a}$ *(556)* | 8660$^{a}$ *(73)* | 3261$^{a}$ *(570)* | 5935$^{a}$ *(241)* | 14 596$^{a}$ *(237)* | 5.01$^{a}$ *(0.05)* | 50.12$^{a}$ *(0.04)* |
| R15 | 9328$^{b}$ *(465)* | 8931$^{a}$ *(236)* | 385$^{b}$ *(252)* | 6369$^{a}$ *(414)* | 15 312$^{b}$ *(227)* | 5.94$^{b}$ *(0.67)* | 50.15$^{a}$ *(0.07)* |
| R30 | 11 008$^{c}$ *(582)* | – | – | – | 18 109$^{c}$ *(339)* | 6.83$^{c}$ *(0.44)* | 50.11$^{a}$ *(0.02)* |
| R45 | 15 585$^{d}$ *(1639)* | – | – | – | 24 344$^{d}$ *(605)* | 6.99$^{c}$ *(0.02)* | 50.14$^{a}$ *(0.04)* |
| CQF | 12 433$^{a}$ *(170)* | 7423$^{d}$ *(129)* | 5010$^{d}$ *(183)* | 4218$^{d}$ *(632)* | 11 641$^{e}$ *(633)* | 5.63$^{b}$ *(0.35)* | 50.16$^{a}$ *(0.08)* |

Means with differing letters in a given row are significantly different ($P < 0.05$, LSD) for that dependent variable; values in parentheses are standard deviation. CQF, commercial quinoa flour; NR, non-roasted; R15, R30, R45 indicate roasting times in minutes.

 

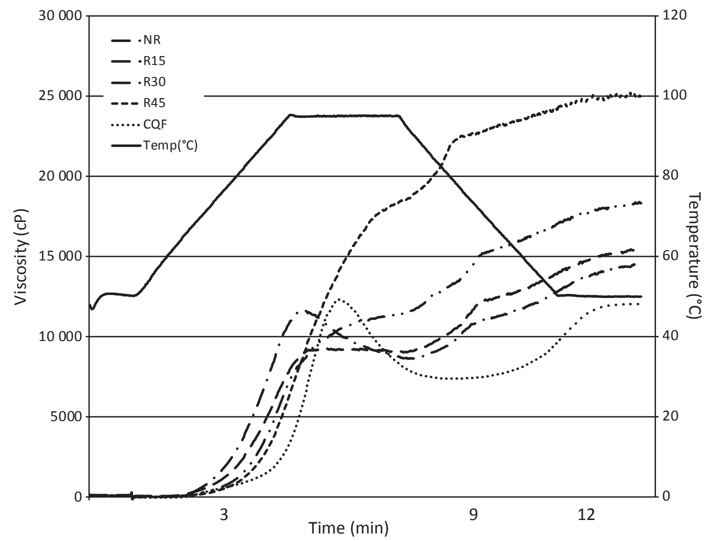


**Figure 1** RVA pasting curves of non-roasted quinoa (NR), roasted quinoa samples (15 min, R15, 30 min, R30, 45 min, R45) and a commercial quinoa flour (CQF).

For example, this flour was analysed directly, whereas previously published data used isolated starch. Additionally, particle size, size distribution and sample preparation affect results. The pasting curve of a pure starch only results from interactions between the test starch and water, as affected by temperature and time. However, understanding the starch behaviour in the context of the flour matrix is more representative. Because of this, a value for one specific parameter may not mean the same thing for a different flour sample, so it is necessary to take all of the values and the shapes of the curves into consideration when comparing samples (Crosbie & Ross, 2007). de la Hera *et al.* (2013) studied the effect of flour particle size on the quality of GF rice cakes and found the finest flours increased their viscosity and reached the peak viscosity later than the coarsest flours.

## Cake analyses

*Sensory evaluation*

Table 3 shows the mean values for the sensory parameters evaluated. There were no significant differences between CCC and NR cakes, which had the highest sensory scores for appearance, colour and firmness (6.9, 7.1 and 6.6, respectively). On flavour and overall acceptability, the CCC had the highest scores (6.5, and 6.4, respectively). Sensory scores for all parameters decreased as roasting time increased, which was unexpected considering roasting has been shown to improve flavour profiles in foods such as peanuts (Buckholz *et al.*, 1980) and coffee (Moon & Shibamoto, 2009). These results are also in contrast with sensory scores reported elsewhere for cakes and muffins, which used milder tasting flours such as rice, corn and potato starch that did not adversely affect the sensory attributes as the roasted quinoa and potentially navy bean flours did. Sae-Eaw *et al.* (2007), using jasmine rice flour to make wheat-free butter cakes, found no differences in the acceptability of appearance (6.7) or crumb colour (6.7); however, the control received higher scores for taste (7.0) and overall liking (7.0). Singh *et al.* (2015) reported overall acceptability scores from 7.0 to 8.4 in GF–EF muffins made with rice flour and modified with varying amounts of jambolan fruit pulp, with or without xanthan gum. Preichardt *et al.* (2011) found overall acceptance scores of 7.7 and 7.1 for GF cakes made with rice and corn flours and the addition of 0.3% and 0.4% xanthan gum, respectively. Sponge cakes made with potato starch, corn and amaranth flours studied by Gambus *et al.* (2009) received good sensory acceptability scores (over 4.5 of 5), as did biscuits and coconut cakes. Kaur *et al.* (2005) used varying amounts of whey protein concentrates (WPC) to replace eggs in EF cakes and saw overall acceptability scores of 7.9–8.2.

*Colour*

$L^*$ values showed no differences among CCC, NR and R15 (35.4), and values between R15 and R30 (36.4), and R30 and R45 (39.4) were not significantly different (Table 4). However, the cake made with quinoa flour roasted for 45 min (R45) which should have resulted in the darkest cake among roasted treatments inexplicably had the highest $L^*$ value compared to NR and R15. $a^*$ values increased with roasting times, while $b^*$ values were unaffected. Noteworthy, colour determination was conducted only on the crumb section. Had the crust been measured, and more dramatic colour changes may have been observed particularly because of the high baking temperature (177 °C). It would be expected that the increased lysine content in quinoa,

 

**Table 3** Mean values of sensory evaluation parameters

| Treatment<br>Parameter | CCC | NR | R15 | R30 | R45 |
|---|---|---|---|---|---|
| Appearance | 6.94a *(2.24)* | 6.73a *(1.85)* | 6.16ac *(2.05)* | 5.82bc *(2.13)* | 5.70bc *(2.07)* |
| Colour | 7.10a *(2.15)* | 6.92ac *(1.68)* | 6.27bc *(2.00)* | 6.12bc *(2.11)* | 5.67b *(2.18)* |
| Texture | 6.62a *(2.28)* | 6.15a *(2.00)* | 5.17b *(2.10)* | 4.96b *(2.35)* | 5.20b *(1.91)* |
| Flavour | 6.47a *(2.17)* | 5.39b *(2.07)* | 4.76bc *(2.12)* | 4.58bc *(2.33)* | 4.38c *(1.86)* |
| Overall | 6.43a *(2.37)* | 5.45b *(2.14)* | 4.96bc *(2.16)* | 4.57bc *(2.28)* | 4.40c *(1.99)* |

Values in parenthesis are standard deviations. CCC, commercial cake, NR, cake with nonroasted quinoa, R15, R30 and R45, cakes with quinoa roasted for 15, 30 and 45 min, respectively. Means with different letters are significantly different ($P < 0.05$).

**Table 4** Mean values of quality evaluation parameters

| Treatment<br>Parameter | CCC | NR | R15 | R30 | R45 |
|---|---|---|---|---|---|
| $L^*$ | 35.43a *(0.98)* | 37.3ac *(0.43)* | 36.39ac *(0.80)* | 37.71bc *(1.23)* | 39.41b *(1.60)* |
| $a^*$ | 1.77a *(0.16)* | 2.68b *(0.19)* | 2.73b *(0.64)* | 3.31bc *(0.41)* | 3.53c *(0.35)* |
| $b^*$ | 0.66a *(0.18)* | 1.55b *(0.31)* | 1.68b *(0.77)* | 1.96b *(0.29)* | 2.28b *(0.37)* |
| Water activity | 0.92a *(0.01)* | 0.94b *(0.01)* | 0.94b *(0.01)* | 0.94b *(0.01)* | 0.94b *(0.01)* |
| Moisture content, % | 47.3a *(0.79)* | 51.25b *(0.84)* | 50.23bc *(1.15)* | 48.65ac *(0.73)* | 49.38c *(0.44)* |
| Firmness, N | 1.79a *(0.16)* | 5.39b *(1.48)* | 5.86b *(0.93)* | 5.98b *(1.21)* | 7.68c *(0.88)* |
| Weight†, g | – | 804.92a *(11.16)* | 796.15a *(11.61)* | 742.98b *(27.27)* | 802.33a *(8.18)* |
| Height, cm | 4.50a *(0.01)* | 7.63b *(0.06)* | 7.27c *(0.21)* | 7.47bc *(0.25)* | 7.70b *(0.10)* |

Values in parenthesis are standard deviations. CCC, commercial cake; NR, cake with nonroasted quinoa; R15, R30 and R45, cakes with quinoa roasted for 15, 30 and 45 min, respectively. Means with different letters are significantly different ($P < 0.05$). †No value for weight of control was included as it was baked in a different pan (cake sheet).

relative to most grains, would result in greater Maillard browning, but inexplicably, this was not the case. Lysine, because of its free primary epsilon amino group, is most susceptible to Maillard browning compared to other amino acids. Based on nutritional analysis of the cakes (data not shown), all cakes contained the same amount of sugar (14 g per serving) and as such the same amount of caramelisation would be expected. In contrast, when comparing with work conducted elsewhere using alternative flours in GF cakes, Preichardt *et al.* (2011) found no differences in $L^*$ (73.5), $a^*$ (−2.9) or $b^*$ (31.2) colour values of GF cakes made with rice and corn flours and xanthan gum when compared with control cakes. Shevkani & Singh (2014) reported increased darkness in GF muffins made with corn starch and varying legume protein sources. Singh *et al.* (2015) observed a decrease in lightness for both crust and crumb of GF–EF muffins made with rice flour modified with increasing amounts of jambolan fruit pulp, with or without xanthan gum.

*Water activity*

Water activity ($a_w$) is the ratio of the vapour pressure of water in product to the vapour pressure of pure water at the same temperature. An important determinant of product shelf-life, water activity was lowest in CCC (0.92) and the same among all quinoa variations (0.94) (Table 4). This level of water activity surpasses the minimum values for growth of moulds, yeast and bacteria (Christen & Smith, 2000), which limits the shelf life of these cakes dramatically. Thus, alternative methods of shelf-life extension, such as cold temperatures, oxygen scavenging technologies, etc., need to be investigated. The lower water activity for the CCC may be due to the presence of humectants such as propylene glycol observed on the product label and possibly greater amounts of salt and sugar. Noteworthy, these levels of water activity in all cases would not contribute significantly to the Maillard reaction as at this high level it would have a diluting effect for the reaction to take place. Singh *et al.* (2015) reported significant decreases in water activity in GF–EF muffins made with rice flour and increasing amounts of jambolan fruit pulp with or without xanthan gum.

*Moisture content*

Values on Table 4 show a slight decreasing trend with the inclusion of longer roasted quinoa flour, with NR and R15 having the same moisture content (51.3%) and all cakes made from roasted quinoa flours having the same moisture content (50.2%). These results can be partially explained by the moisture content of the nonroasted and all roasted quinoa flours, which showed a decrease from 11.1% (NR) to 0.2% (R45) (data not shown). Preichardt *et al.* (2011) found no differences in moisture content (36.1%) between the GF cakes and the control.

*Firmness*

An increasing trend was observed with the inclusion of longer roasted flours, with R45 having the highest firmness (7.7 N), while NR, R15 and R30 had the same and lower firmness (5.9 N) (Table 4). The commercial product (CCC) was the softest of all products tested (1.8 N). From the pasting data, it can be observed that the R45 quinoa flour had the highest final viscosity (24 344 cP), which may have contributed to hardening of the cakes along with the decreasing moisture content with roasting. Singh *et al.* (2015) reported an initial increase in firmness followed by a decrease in GF–EF muffins made with rice flour with increasing amounts of jambolan fruit pulp, with or without xanthan gum.

*Weight and height*

As seen on Table 4, no changes in weight were seen among NR, R15 and R45 (805 g), while R30 was the lowest at 743 g, due to a much larger standard deviation possibly resulting from human error in collecting weight data. Height was lowest in R15 (7.3 cm), while R45 had the highest (7.7 cm). Given the completely different nature of the two recipes, CCC weight was not measured along with the AF–GF quinoa cakes. It is suspected that the grapeseed oil, navy bean and quinoa flours along with whole-grain milk used in these preparations may have contributed emulsifiers and hydrocolloids, to assist with the proper rising of the cakes. In a study by Arozarena *et al.* (2001), EF yellow cakes prepared with a mixture of mono- and diglycerides along with emulsifiers and/or hydrocolloids resulted in increased cake height with the addition of xanthan gum.

*Cake nutritional information*

Experimental cakes contained 190 calories (NR) and 200 calories (R15, R30 and R45); 17 g of whole grains; 4 g of total dietary fibre (TDF) which allows a label claim of excellent source of fibre; 4 g of protein for NR and 5 g for R15, R30 and R45; 31 g of carbohydrates for NR and 32 g for R15, R30 and R45; 7 g of total fat; 1 g of saturated fat for NR and 0.5 g for R15, R30 and R45; 0 mg of cholesterol; and 14 g of sugar and 360 mg of sodium per 80 g serving. The nutritional information for the commercial chocolate cake without icing was unavailable.

## Conclusions and future research

Results from this study underlined the effect of different roasting times of quinoa and the application of the resulting flours in an allergen-free, gluten-free cake formulation. Roasting dramatically improved pasting properties such as final viscosity or paste stability and setback or degree of retrogradation after heating, shearing and cooling. Gluten-free and allergen-free baked goods in particular may benefit from a blend of roasted and nonroasted quinoa flours when gelatinisation is needed but retrogradation must be limited for functionality and shelf-life purposes. These cake formulations contained 17 g of whole grains per RACC and were a good source of fibre, which help fulfill the need for higher nutrient quality ingredients as a GF dietary pattern is often characterised by a reduced intake of complex carbohydrates, dietary fibre, vitamins and minerals. However, more research is required to improve sensory characteristics despite the challenges faced in the absence of structural proteins, and these data can be used as a reference tool during product formulation.

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## References

AACC (2000). *Approved Methods of American Association of Cereal Chemists*, 10th edn. St. Paul, MN: The American Association of Cereal Chemists.

Abugoch James, L.E. (2009). Quinoa (*Chenopodium quinoa* Willd.): composition, chemistry, nutritional, and functional properties. *Advances in Food and Nutrition Research*, **58**, 1–31.

Abugoch, L.E., Romero, N., Tapia, C.A., Silva, J. & Rivera, M. (2008). Study of some physicochemical and functional properties of quinoa (chenopodium quinoa willd) protein isolates. *Journal of Agricultural and Food Chemistry*, **56**, 4745–4750.

Ahamed, N.T., Singhal, R.S., Kulkarni, P.R. & Pal, M. (1998). A lesser-known grain, *Chenopodium quinoa*: review of the chemical composition of its edible parts. *Food and Nutrition Bulletin*, **19**, 61–70.

Alvarez-Jubete, L., Arendt, E.K. & Gallagher, E. (2010). Nutritive value of pseudocereals and their increasing use as functional gluten-free ingredients. *Trends in Food Science & Technology*, **21**, 106–113.

Arozarena, I., Bertholo, H., Empis, J., Bunger, A. & Sousa, I. (2001). Study of the total replacement of egg by white lupine protein, emulsifiers and xanthan gum in yellow cakes. *European Food Research and Technology*, **213**, 312–316.

Ashwini, A., Jyotsna, R. & Indrani, D. (2009). Effect of hydrocolloids and emulsifiers on the rheological, microstructural and quality characteristics of eggless cake. *Food Hydrocolloids*, **23**, 700–707.

Astier, C., Moneret-Vautrin, D.A., Puillandre, E. & Bihain, B.E. (2009). First case report of anaphylaxis to quinoa, a novel food in France. *Allergy*, **64**, 819–820.

Bhargava, A., Shukla, S. & Ohri, D. (2006). *Chenopodium quinoa*—an Indian perspective. *Industrial Crops and Products*, **23**, 73–87.

Brady, K., Ho, C.-T., Rosen, R.T., Sang, S. & Karwe, M.V. (2007). Effects of processing on the nutraceutical profile of quinoa. *Food Chemistry*, **100**, 1209–1216.

Buckholz, L.L., Daun, H., Stier, E. & Trout, R. (1980). Influence of roasting time on sensory attributes of fresh roasted peanuts. *Journal of Food Science*, **45**, 547–554.

del Castillo, M.D., Ames, J.M. & Gordon, M.H. (2002). Effect of roasting on the antioxidant activity of coffee brews. *Journal of Agricultural and Food Chemistry*, **50**, 3698–3703.

Christen, G.L. & Smith, J.S. (2000). Food chemistry: principles and applications. Science Technology System West Sacramento, CA, USA.

Comai, S., Bertazzo, A., Bailoni, L., Zancato, M., Costa, C.V.L. & Allegri, G. (2007). The content of proteic and nonproteic (free and protein-bound) tryptophan in quinoa and cereal flours. *Food Chemistry*, **100**, 1350–1355.

Crisafulli, G., Caminiti, L. & Pajno, G.B. (2012). Oral desensitization for immunoglobulin E-mediated milk and egg allergies. *The Israel Medical Association Journal: IMAJ*, **14**, 53–56.

Crosbie, G.B. & Ross, A.S. (2007). *The RVA Handbook*. Pp. 8, 152. St. Paul, MN: AACC International.

Daglia, M., Papetti, A., Gregotti, C., Berte, F. & Gazzani, G. (2000). In vitro antioxidant and ex vivo protective activities of green and roasted coffee. *Journal of Agricultural and Food Chemistry*, **48**, 1449–1454.

Dini, I., Tenore, G.C. & Dini, A. (2010). Antioxidant compound contents and antioxidant activity before and after cooking in sweet and bitter *Chenopodium quinoa* seeds. *LWT – Food Science and Technology*, **43**, 447–451.

Gahlawat, P. & Sehgal, S. (1993). Antinutritional content of developed weaning foods as affected by domestic processing. *Food Chemistry*, **47**, 333–336.

Gambus, H., Gambus, F., Pastuszka, D. *et al*. (2009). Quality of gluten-free supplemented cakes and biscuits. *International Journal of Food Sciences and Nutrition*, **60**(Suppl 4), 31–50.

Gómez, M., Oliete, B., Rosell, C.M., Pando, V. & Fernández, E. (2008). Studies on cake quality made of wheat–chickpea flour blends. *LWT – Food Science and Technology*, **41**, 1701–1709.

Gorgônio, C.M.d.S., Pumar, M. & Mothé, C.G. (2011). Macrocospic and physiochemical characterization of a sugarless and gluten-free cake enriched with fibers made from pumpkin seed (*Cucurbita maxima*, L.) flour and cornstarch. *Food Science and Technology (Campinas)*, **31**, 109–118.

Gorinstein, S., Lojek, A., Číž, M. *et al*. (2008). Comparison of composition and antioxidant capacity of some cereals and pseudocereals. *International Journal of Food Science and Technology*, **43**, 629–637.

Griffith, L.D. & Castell-Perez, M.E. (1998). Effects of roasting and malting on physicochemical properties of select cereals and legumes. *Cereal Chemistry*, **75**, 780–784.

Gularte, M.A., de la Hera, E., Gómez, M. & Rosell, C.M. (2012a). Effect of different fibers on batter and gluten-free layer cake properties. *LWT – Food Science and Technology*, **48**, 209–214.

Gularte, M.A., Gómez, M. & Rosell, C.M. (2012b). Impact of legume flours on quality and in vitro digestibility of starch and protein from gluten-free cakes. *Food and Bioprocess Technology*, **5**, 3142–3150.

Hallert, C., Grant, C., Grehn, S. *et al*. (2002). Evidence of poor vitamin status in coeliac patients on a gluten-free diet for 10 years. *Alimentary Pharmacology & Therapeutics*, **16**, 1333–1339.

de la Hera, E., Martinez, M., Oliete, B. & Gómez, M. (2013). Influence of flour particle size on quality of gluten-free rice cakes. *Food and Bioprocess Technology*, **6**, 2280–2288.

Hoover, L. (2009). No wheat no dairy no problem : delicious recipes for people with food allergies/sensitivity and everyone who is looking for healthy alternatives. The Cookbook I Wish I Had! Bloomington, IN, IUniverse.

Hussain, S.S.A. & Al-Oulabi, R.A. (2009). Studying the possibility of preparing an egg-free or egg-less cake. *International Journal of Engineering and Technology*, **1**, 324–329.

Jancurová, M., Minarovicova, L. & Dandár, A. (2009). Quinoa – a review. *Czech Jurnal of Food Sciences*, **27**, 71–79.

Kaur, A.P., Kaur, A. & Bakhshi, A.K. (2005). Development of egg-free cakes by using whey protein concentrates. *Advances in Food Sciences*, **27**, 2–5.

Kim, W., Choi, S., Kerr, W., Johnson, J. & Gaines, C. (2004). Effect of heating temperature on particle size distribution in hard and soft wheat flour. *Journal of Cereal Science*, **40**, 9–16.

Koziol, M.J. (1992). Chemical composition and nutritional evaluation of quinoa (*Chenopodium quinoa* Willd.). *Journal of Food Composition and Analysis*, **5**, 35–68.

Lindeboom, N., Chang, P.R., Falk, K.C. & Tyler, R.T. (2005). Characteristics of starch from eight quinoa lines. *Cereal Chemistry*, **82**, 216–222.

Lintschinger, J., Fuchs, N., Moser, H. *et al*. (1997). Uptake of various trace elements during germination of wheat, buckwheat and quinoa. *Plant Foods for Human Nutrition (Formerly Qualitas Plantarum)*, **50**, 223–237.

Martins, A.C.C.L. & Gloria, M.B.A. (2010). Changes on the levels of serotonin precursors – tryptophan and 5-hydroxytryptophan – during roasting of Arabica and Robusta coffee. *Food Chemistry*, **118**, 529–533.

Matos, M.E. & Rosell, C.M. (2014). A review: understanding gluten free dough for reaching breads with physical quality and nutritional balance. *Journal of the Science of Food and Agriculture*, **95**, 653–661.

Moon, J.K. & Shibamoto, T. (2009). Role of roasting conditions in the profile of volatile flavor chemicals formed from coffee beans. *Journal of Agricultural and Food Chemistry*, **57**, 5823–5831.

Nicoli, M.C., Anese, M., Manzocco, L. & Lerici, C.R. (1997). Antioxidant properties of coffee brews in relation to the roasting degree. *LWT – Food Science and Technology*, **30**, 292–297.

Oenning, G., Juillerat, M.A., Fay, L. & Asp, N.-G. (1994). Degradation of oat saponins during heat processing – effect of pH, stainless steel, and iron at different temperatures. *Journal of Agricultural and Food Chemistry*, **42**, 2578–2582.

Ogungbenle, H.N. (2003). Nutritional evaluation and functional properties of quinoa (*Chenopodium quinoa*) flour. *International Journal of Food Sciences and Nutrition*, **54**, 153–158.

Omary, M.B., Fong, C., Rothschild, J. & Finney, P. (2012). Effects of germination on the nutritional profile of gluten-free cereals and pseudocereals: a review. *Cereal Chemistry*, **89**, 1–14.

Oshodi, A.A., Ogungbenle, H.N. & Oladimeji, M.O. (1999). Chemical composition, nutritionally valuable minerals and functional properties of benniseed (*Sesamum radiatum*), pearl millet (*Pennisetum typhoides*) and quinoa (*Chenopodium quinoa*) flours. *International Journal of Food Sciences and Nutrition*, **50**, 325–331.

Park, S., Ha, K.-Y. & Shin, M. (2012). Properties and qualities of rice flours and gluten-free cupcakes made with higher-yield rice varieties in Korea. *Food Science and Biotechnology*, **21**, 365–372.

Prakash, D. & Pal, M. (1998). *Chenopodium quinoa*: changes in amino acid composition in seed during maturity. *International Journal of Food Sciences and Nutrition*, **49**, 285–288.

Preichardt, L.D., Vendruscolo, C.T., Gularte, M.A. & Moreira, A.d.S. (2011). The role of xanthan gum in the quality of gluten free cakes: improved bakery products for coeliac patients. *International Journal of Food Science and Technology*, **46**, 2591–2597.

Qian, J. & Kuhn, M. (1999). Characterization of *Amaranthus cruentus* and *Chenopodium quinoa* starch. *Starch – Stärke*, **51**, 116–120.

Ratnayake, W.S., Geera, B. & Rybak, D.A. (2012). Effects of egg and egg replacers on yellow cake product quality. *Journal of Food Processing and Preservation*, **36**, 21–29.

 

Repo-Carrasco, R., Espinoza, C. & Jacobsen, S.E. (2003). Nutritional value and use of the Andean crops quinoa (*Chenopodium quinoa*) and kaniwa (*Chenopodium pallidicaule*). *Food Reviews International*, **19**, 179–189.

Repo-Carrasco-Valencia, R.A.M., Encina, C.R., Binaghi, M.J., Greco, C.B. & Ronayne de Ferrer, P.A. (2010). Effects of roasting and boiling of quinoa, kiwicha and kañiwa on composition and availability of minerals in vitro. *Journal of the Science of Food and Agriculture*, **90**, 2068–2073.

Richardson, D.G. & Ebrahem, K. (1997). Hazelnut kernel quality as affected by roasting temperatures and duration. *Acta Horticulturae*, **445**, 301–304.

Ronda, F., Gómez, M., Caballero, P.A., Oliete, B. & Blanco, C.A. (2009). Improvement of quality of gluten-free layer cakes. *Food Science and Technology International*, **15**, 193–202.

Ronda, F., Oliete, B., Gómez, M., Caballero, P.A. & Pando, V. (2011). Rheological study of layer cake batters made with soybean protein isolate and different starch sources. *Journal of Food Engineering*, **102**, 272–277.

Sae-Eaw, A., Chompreeda, P., Prinyawiwatkul, W. *et al*. (2007). Acceptance and purchase intent of US consumers for nonwheat rice butter cakes. *Journal of Food Science*, **72**, S92–S97.

Sapone, A., Bai, J.C., Ciacci, C. *et al*. (2012). Spectrum of gluten-related disorders: consensus on new nomenclature and classification. *BMC Medicine*, **10**, 13.

Sedej, I., Sakač, M., Mandić, A. *et al*. (2011). Quality assessment of gluten-free crackers based on buckwheat flour. *LWT – Food Science and Technology*, **44**, 694–699.

Sharma, P., Gujral, H.S. & Rosell, C.M. (2011). Effects of roasting on barley β-glucan, thermal, textural and pasting properties. *Journal of Cereal Science*, **53**, 25–30.

Shevkani, K. & Singh, N. (2014). Influence of kidney bean, field pea and amaranth protein isolates on the characteristics of starch-based gluten-free muffins. *International Journal of Food Science and Technology*, **49**, 2237–2244.

Sicherer, S.H. & Sampson, H.A. (2006). 9. Food allergy. *The Journal of Allergy and Clinical Immunology*, **117**, S470–S475.

Singh, J.P., Kaur, A., Shevkani, K. & Singh, N. (2015). Influence of jambolan (*Syzygium cumini*) and xanthan gum incorporation on the physicochemical, antioxidant and sensory properties of gluten-free eggless rice muffins. *International Journal of Food Science and Technology*, **5**, 1190–1197.

Tang, H., Watanabe, K. & Mitsunaga, T. (2002). Characterization of storage starches from quinoa, barley and adzuki seeds. *Carbohydrate Polymers*, **49**, 13–22.

United Nations (2012). United Nations Resolution adopted by the General Assembly 66/221 International Year of Quinoa, 2013.

Vega-Gálvez, A., Miranda, M., Vergara, J., Uribe, E., Puente, L. & Martínez, E.A. (2010). Nutrition facts and functional potential of quinoa (*Chenopodium quinoa* willd.), an ancient Andean grain: a review. *Journal of the Science of Food and Agriculture*, **90**, 2541–2547.

Volta, U., Caio, G., Tovoli, F. & De Giorgio, R. (2013). Non-celiac gluten sensitivity: questions still to be answered despite increasing awareness. *Cellular & Molecular Immunology*, **10**, 383–392.

Wood, S.G., Lawson, L.D., Fairbanks, D.J., Robison, L.R. & Andersen, W.R. (1993). Seed lipid content and fatty acid composition of three quinoa cultivars. *Journal of Food Composition and Analysis*, **6**, 41–44.

Wright, K.H., Huber, K.C., Fairbanks, D.J. & Huber, C.S. (2002a). Isolation and characterization of *Atriplex hortensis* and sweet *Chenopodium quinoa* starches. *Cereal Chemistry*, **79**, 715–719.

Wright, K.H., Pike, O.A., Fairbanks, D.J. & Huber, C.S. (2002b). Composition of *Atriplex hortensis*, sweet and bitter *Chenopodium quinoa* seeds. *Journal of Food Science*, **67**, 1383–1385.

Yotaro, K. (2002). Nutritional characteristics of pseudocereal amaranth and quinoa: alternative foodstuff for patients with food allergy. *Journal of Japanese Society of Nutrition and Food Science*, **55**, 299–302.

Zhang, D. & Hamauzu, Y. (2004). Phenolics, ascorbic acid, carotenoids and antioxidant activity of broccoli and their changes during conventional and microwave cooking. *Food Chemistry*, **88**, 503–509.

Zhu, N., Sheng, S., Li, D. *et al*. (2001). Antioxidative flavonoid glycosides from quinoa seeds (*Chenopodium quinoa* Willd) *Journal of Food. Lipids*, **8**, 37–44.

Zia-ur-Rehman, Z., Islam, M. & Shah, W.H. (2003). Effect of microwave and conventional cooking on insoluble dietary fibre components of vegetables. *Food Chemistry*, **80**, 237–240.

 